First Data from the Prehistoric Site Complex of Cueva del Arco (Murcia, Spain)

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Abstract

The southern Iberian Peninsula is a key area for understanding the timing and patterns of the Middle-to-Upper Palaeolithic transition. Recently, the excavation and study of new sites have provided new insights on this topic. The aim of this paper is to introduce Cueva del Arco, a site complex featuring distinct caves and rock shelters. Cueva del Arco is located at a short distance from the Almadenes gorge (Cieza, Spain) and preserves both Middle and Upper Palaeolithic deposits and assemblages, as well as rock art. Despite being known since the 1990s for its Palaeolithic rock art, systematic fieldwork was never undertaken at the site until recently. We here report the first results of a research programme that includes the systematic excavation of several cavities belonging to the Cueva del Arco complex, focusing on the location and context of the site, its stratigraphy and chronology, and site formation. Research at the site is still ongoing, but preliminary results suggest that the data from Cueva del Arco will provide new clues to the current debate on the transition from Neanderthals to anatomically modern humans in southern Europe.

Keywords Iberian Peninsula · Middle Palaeolithic · Upper Palaeolithic · Cave site · Geoarchaeology · Archaeological micromorphology

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Introduction

The transition between Neanderthals and anatomically modern humans (AMH), which is archaeologically placed at the crossroads between the Middle and Upper Palaeolithic (MUP), is one of the most important issues for understanding the past of humankind. This is undoubtedly one of the main debates in recent decades at a European level, especially in the last few years thanks to the open question about the symbolic capacities of Neanderthal populations (Zilhão et al., 2010; Caron et al., 2011; Finlayson et al., 2012; Hublin et al., 2012; Pike et al., 2012; Hoffman et al., 2018; White et al., 2019).

The Iberian Peninsula is precisely where a good part of the new data is being generated making it possible to place the MUP transition at the centre of international debates. The data extracted from the DNA of the Neanderthals from the Cueva del Sidrón (de la Rasilla et al., 2014) and the dates obtained for samples of rock art and symbolism at various peninsular sites (Zilhão et al., 2010; Hoffman et al., 2018) have made Spain the focus of the most advanced research. The persistence of these populations in the peninsula and their late disappearance is fully relevant to the fate of these humans and their replacement by AMH. These matters have made the Iberian Peninsula the core of the debate about Neanderthals (Finlayson et al., 2006; Galván et al., 2014; Zilhão et al., 2017; Wolf et al., 2018; Vidal-Cordasco et al., 2022). Additionally, there are new contributions related to various aspects of the subsistence and economy of Neanderthals, the complexity of these humans in relation, for example, to the supply of raw materials, and the confirmation of their marine diet as a complement to a terrestrial one (Bicho, 2004, 2004a; Zilhão et al., 2020; Barbieri et al., 2022). Some of the main results that have had the greatest impact come precisely from excavations at sites in the southeast of the peninsula, such as Cueva Antón, Cueva de los Aviones and Abrigo de La Boja (Zilhão et al., 2010, 2017; Hoffman et al., 2018).

For all of the above, it is essential to collect new data on the MUP transition assessing patterns, chronology and environmental context, as well as confirming existing models.

In this paper, we present the site of Cueva del Arco, a recently excavated complex of cave sites located in the province of Murcia, southeastern Spain, which bears both Middle and Upper Palaeolithic deposits as well as rock art. Today, the site is known only through local articles or grey literature (Salmerón Juan et al., 1997, 1998, 2018; Martín-Lerma and Román Monroig, 2018). Besides being a rather impressive landmark, Cueva del Arco preserves a very promising stratigraphic record, which will be presented in this paper. This contribution is focussed on the stratigraphy and chronology of the site, as the complete study of archaeological assemblages is still ongoing.

Site Presentation

Location and Context of Cueva del Arco

Cueva del Arco is located in the municipality of Cieza, Murcia (Spain), at an elevation between *c.* 335 and 350 m asl (above modern sea level—see Fig. 1), on the left side of

the Barranco de la Tabaquera. This is a short ravine, usually dry throughout the annual cycle and draining to the River Segura, one the main water courses of this sector of the Iberian Peninsula. The deeply incised Almadenes gorge, at the bottom of which the river flows, is found a few hundred metres from Cueva del Arco. The Almadenes gorge is known for its high density of archaeological cave sites and prehistoric art, both included in the World Heritage List, within the complex of the "Rock Art of the Mediterranean Basin on the Iberian Peninsula" (Lomba Maurandi, 2018).

The Cueva del Arco complex includes a dense cluster of karstic forms situated around a sinkhole limited to the south by a well-developed rock bridge, which has a minimum span of *c.* 10 m and a height of *c.* 8 m. This impressive landmark gives the name to the site, as it means "cave of the arch" (Fig. 2). The place was already known for the existence of rock art painted on its walls (see Lomba Maurandi, 2018 for a review). However, systematic fieldwork at Cueva del Arco only began in 2015.

The complex is found along the left (northern) side of the Barranco de la Tabaquera and consists of two distinct locations, Arco I and Arco II. The former includes five karstic cavities that have been named with capital letters (A to E). The origin and evolution of the karstic network from which the Cueva del Arco complex derived have not yet been studied. Nonetheless, the strong development of surface morphologies (dry valleys, sinkholes, rock shelters and caves with distinct size and shape) and the occurrence of cave sediments and speleothems encrusted along the walls and slopes of the Barranco de la Tabaquera point to the existence of a complex karstic system formed in the carbonate rocks outcropping in the area.

The site is located on a small plateau, partly dissected by erosion, found between the deep incision of the Almadenes canyon to the north and the tectonically raised Sierra de la Palera (654 m asl) to the south. The plateau is modelled into Cretaceous sedimentary rocks belonging to the so-called "Internal Pre-Betics" domain (IGME 1972). The cave complex is located at the boundary between two distinct geological formations. Massive whitish limestone, dated from the Coniacian, outcrops to the East of the cave, while massive dolostone (dolomicrite) dated from the Turonian is found to its west.

The geomorphological landscape around Cueva del Arco shows evidence of fluviokarstic dynamics (such as the Almadenes gorge) and strong karstic dissolution (dry valleys, sinkholes and Karren microforms are widespread in the surroundings). Around the site, rocky outcrops are dominant and no significant surface sediments or soil covers have been observed, with the exception of recent coarse scree deposits at the base of rock walls or occasional rounded cobbles, scattered in the valley bottom. Quaternary sediments have only been detected as infilling of karstic morphologies and cavities.

History of Research

In 1993, three cavities with Palaeolithic rock art were discovered by the Almadenes speleology group in the vicinity of the Almadenes Canyon, namely Cueva de Jorge, Cueva de las Cabras and Cueva del Arco (Salmerón Juan et al., 1998; 1999).
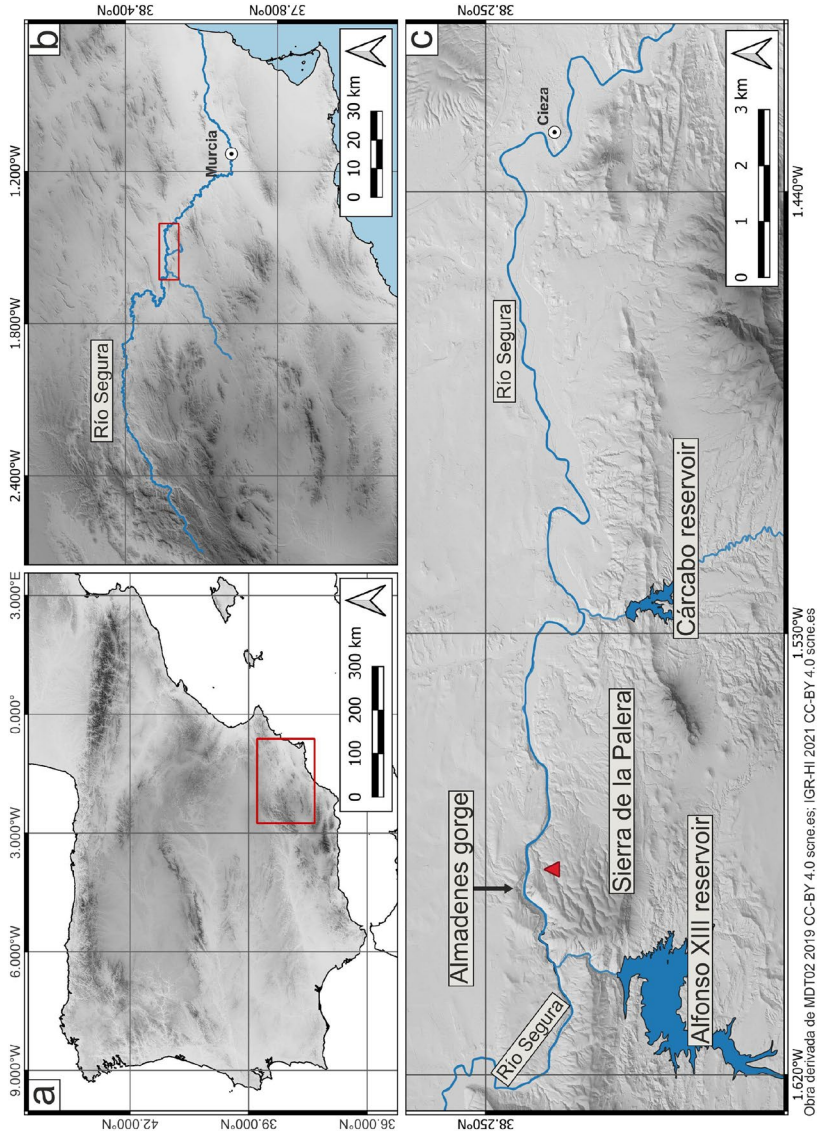
Fig. 1 Cueva del Arco (red triangle): site location in the Iberian Peninsula (**a**), within the Murcia Region (**b**) and with respect to the Almadenes gorge (**c**). Elaboration by J. Armellini from DTM MDT02 2019 and IGR-HI 2021 (both CC-BY 4.0), scne.es
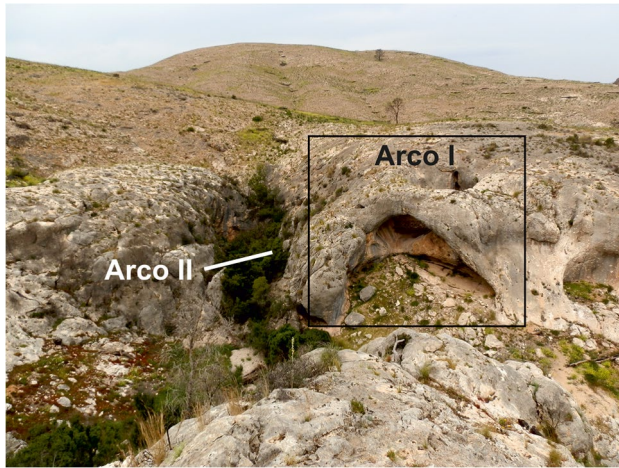
Fig. 2 Cueva del Arco and its two main sub-complexes (Arco I and Arco II), seen from the south. Picture and elaboration by D. Angelucci

At Cueva del Arco, the rock art can be found in Cave E, a narrow gallery 1.5 m wide, 15 m deep and 8 m high. The motifs consist of two horse protomes and some geometric lines visible at the entrance of the cavity, a complete doe, and remains of a possible horse about 8 m from the entrance. The style of the horses, with marked ears, a well-defined jaw and a duck beak-shaped muzzle, allow us to ascribe these manifestations to the Solutrean, as is also the case for the doe (see Salmerón Juan et al., 1998, 2018).

A few metres from Cueva del Arco there is a small karstic hole named Arco II, in which there are two wild goats represented frontally, several dots and other indeterminate signs. The style of the figures has allowed them to be assigned to the Upper Magdalenian (Salmerón Juan et al., 1998, 2018).

Despite these rock art discoveries, archaeological materials from Cueva del Arco were initially very scarce. Only a "limestone mill, with an abraded surface and abundant remains of red pigment, covered by a layer of calcite that authenticates its great antiquity" was uncovered (Salmerón Juan et al., 1998: 107).

After this, the site ceased to be the subject of research, until, in 2014, as part of a project related to the dating of Palaeolithic art, the Cueva del Arco was visited and several lithic artefacts were found at Cave A—including a flint blade with clear Palaeolithic features.

The discovery of Palaeolithic materials increased interest in the site, because, as well as its rock art, it now had tangible evidence of Palaeolithic occupation and was one of the few sites on the Mediterranean coast of the Iberian Peninsula with both Palaeolithic occupation and rock art. This fact led to the idea of carrying out a general cleaning of the surface and the excavation of a small test pit to find the possible archaeological succession of the cavity in 2015. The results of this preliminary test allowed us to confirm the importance of the site and plan the systematic exploration of the Cueva del Arco complex.

Materials and Methods

In the seven field campaigns carried out to date, work has been done in two of the cavities making up the Cueva del Arco complex: Cave A and Cave D (Figs. 3 and 4). The archaeological assemblages recovered, the dates obtained and the documented sequence allow us to offer a reliable approach to the different human occupations of the cavities, corresponding to distinct periods from the Middle Palaeolithic to the early Neolithic periods.

The main excavation was carried out in Cave A, affecting about 50 m². This is the place where the Palaeolithic occupations have been best preserved. In 28 m², the base layers were reached and the entire preserved succession was documented. In the rest, the upper units have been excavated, leaving the Middle Palaeolithic surface at ground level.

In Cave D, an area of 20 m² has been excavated in the campaigns from 2015 to 2018. At surface level, an occupation corresponding to the early Neolithic has been documented. Below this occupation, the recovered materials are dispersed and appear to be in a secondary position, although everything indicates that they belong to the Upper Palaeolithic.

Methodologically, the area of the various cavities has been gridded into squares with a 1 m side, and each of these has been subdivided into four squares with a 50 cm side, which is the base surface unit of work. The excavation was carried out using artificial spits 5 cm thick, always taking into account possible natural stratigraphic changes. It has been possible to document the contact between the Upper Palaeolithic layers and those of the Middle Palaeolithic across most of the area.

The materials recovered (lithic industry, bone remains, pottery, charcoal fragments, etc.) have been located three-dimensionally in relation to a general reference point and have been recorded individually. All lithic artefacts larger than 15 mm and bone fragments larger than 30 mm have been located and individualised. In addition, photographic documentation and a georeferenced 3D reconstruction of each of the layers have been carried out.

Meanwhile, charcoal fragments, microfaunal remains and other small items have been recovered manually during the excavation and sieving process, and sediment samples have been saved for flotation and recovery of all elements that can be analysed. Likewise, samples have been taken for the palynological and phytolith study, both in the stratigraphic succession and in combustion structures. Charcoal fragments for radiocarbon analysis were dry-collected during excavation and sent to two distinct laboratories for dating (ETH, Zurich, Switzerland, and VERA, Vienna, Austria).

In some squares, especially in the upper layers, burrows of small mammals (especially rabbits) have been documented, excavated and separated individually to avoid contamination of the prehistoric succession.

The main archaeological materials recovered, described in the following section, consist of remains of the lithic industry, animal bones and charcoal fragments, with the addition of some pottery fragments from the upper layers. Combustion structures are also detected in all layers.

Fig. 3 Cueva del Arco: excavation at Cave A (**1** and **2**) and Cave D (**3** and **4**). Pictures **1**, **2** and **4** were taken during the 2019 field campaign, while picture **3** is from 2019. Pictures and elaboration by I. Martín and D. Román
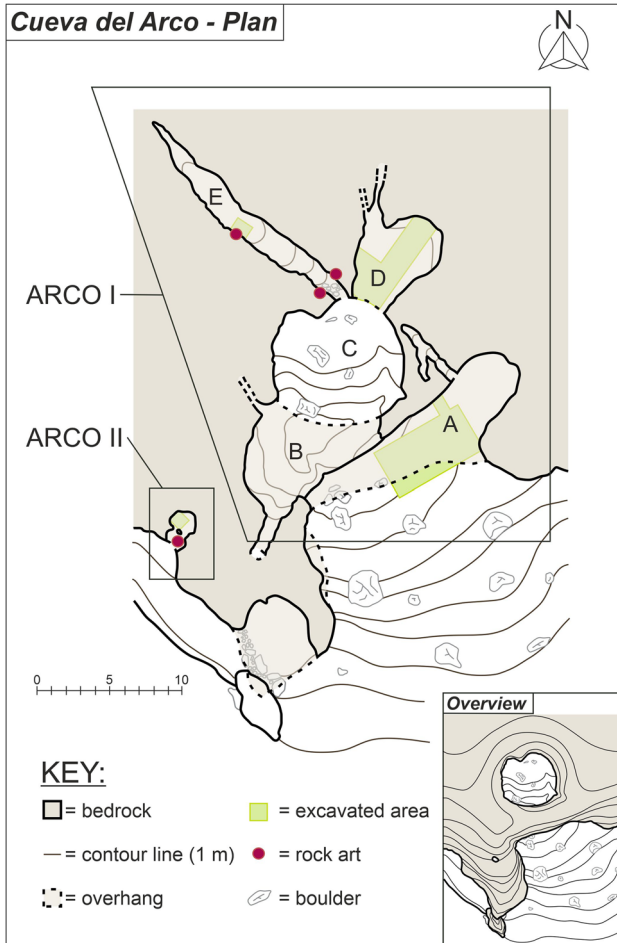
Fig. 4 Cueva del Arco: general plan of the site, reporting the loci Arco I and Arco II, main cavities (capital letters), excavated areas and position of rock art (modified after Salmerón Juan et al., (1998); elaboration by J. Armellini)

The geoarchaeological study of Cueva del Arco has included non-systematic geological, geomorphological and soil survey around the site, field description of the deposits and sampling for archaeological micromorphology and other analyses.

The sedimentary, pedogenetic, diagenetic and archaeological characteristics of all the units under excavation and cross-sections exposed were systematically described. Colour was determined in moist conditions following the *Munsell Soil Color Book*. For identification of layers and stratigraphic purposes, besides units of stratification defined during the excavation, geoarchaeological field units (as outlined in Angelucci, 2002—GFU hereafter) were used in order to assess internal variability of the units identified during fieldwork. The study of the thin

sections from the archaeological deposits is in progress, and only preliminary data on the archaeological micromorphology will be provided here.

Undisturbed samples of sediment were collected to assess the sin- and post-depositional processes involved in the formation of the archaeological deposit; three samples come from Cave D and two come from Cave E (see Table 1). The thin sections were prepared at "Servizi per la Geologia" laboratory (Piombino, Italy), following these three stages: (i) impregnation with resin, styrene and hardener, (ii) curing and (iii) cutting into cm-thick slabs and final preparation of 25 µm sections, measuring 95 mm × 55 mm. The thin sections were observed under the petrographic microscope of the LaBAAF (Laboratorio Bagolini for Archaeology, Archaeometry and Photography, University of Trento) at magnifications between ×20 and ×1000 using plane-polarised (PPL) and crossed-polarised light (XPL). Primary fluorescence observation was also performed using both ultraviolet and blue light. The description of the thin sections follows the guidelines proposed by Bullock et al. (1985) and Stoops (20032021).

Results

The Caves and Their Infilling

The Cueva del Arco complex includes distinct karstic cavities clustered around the natural bridge (named "Arco I") and in its surroundings, in particular along the walls of the collapsed karstic valley to the east of the bridge ("Arco II", see Fig. 2). Three main cavities (Fig. 4) are accessible from the large karstic hollow (Cave C) behind (upstream) the natural bridge, which shows sub-circular shape and a diameter of *c.* 10 m: to its southeast, Cave B, a *c.* 5-m-wide, tafoni-like rock shelter, without sedimentary infilling, which continues to the southeast in form of a karstic gallery (approximately towards Arco II); to the northeast, Cave E, a narrow cavity developed along a subvertical fissure, with rock art painted along its walls (Fig. 5); to the north, Cave D, one of the cavities that has been explored archaeologically. Cave A is located below the natural bridge and forms a relatively large rock shelter, situated along the left slope of Barranco de la Tabaquera, a talus scree scattered with fallen limestone boulders. Cave A deposit features both Upper and Middle Palaeolithic cultural assemblages.

Table 1 Cueva del Arco. List of micromorphological samples. Key: year, year of collection of sample; sq., square; all thin sections measure 9.5 cm by 5.5 cm and are uncovered

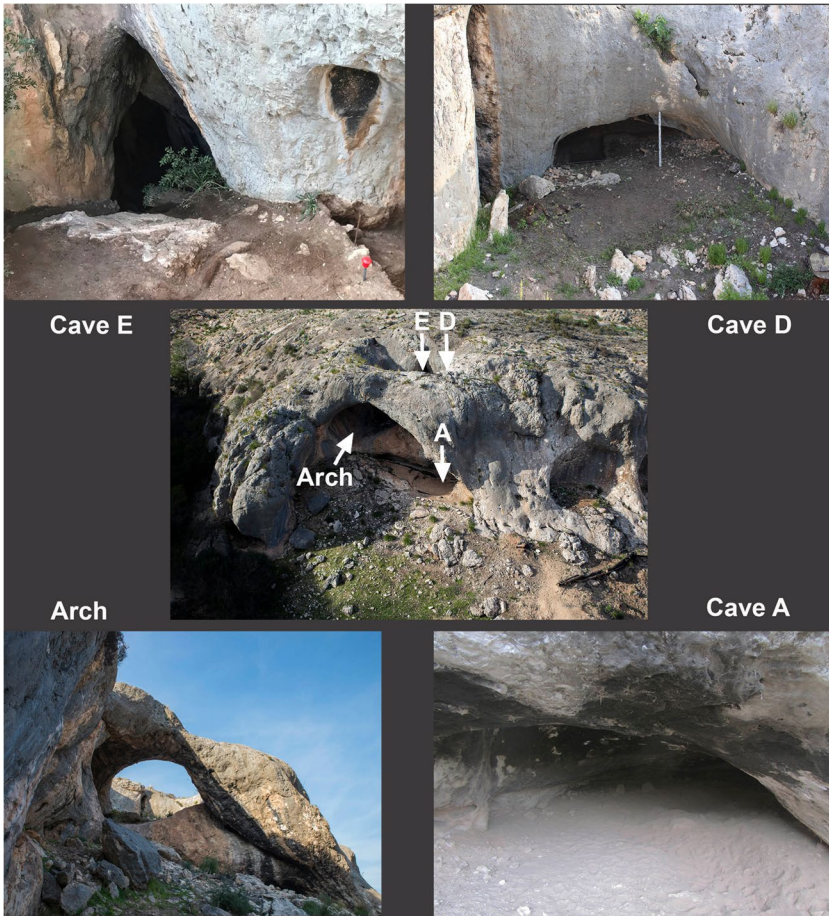| Label	Cave	Year	GFU	Provenance
ARCO1701	D	2017	D3	Cross-section 3, sq. C11
ARCO1902	D	2019	D2b	sq. B7
ARCO1903	D	2019	D2a	sq. B5
ARCO1901	E	2019	E2	Test pit
ARCO1904	E	2019	E1+E2	Test pit

Fig. 5 Cueva del Arco: the distinct caves of Arco I. Cave E (top left), Cave D (top right), overall view of Arco I (centre), the natural bridge (bottom left) and Cave A (bottom right). Scale is reported in Fig. 4. Pictures and elaboration by I. Martín and D. Román

Cueva del Arco: Cave A

The succession of Cave A is the most complete and the richest among the deposits filling the distinct cavities of Cueva del Arco. This is the reason why field campaigns have mostly been directed at the excavation of Cave A.

Stratigraphy of Cave A

Four distinct excavation units compose the succession of Cave A (excavation units I, II and III, and the bottom part of the succession, which is unnamed archaeologically, see Fig. 6). The deposit is characterized by the presence of common to abundant limestone fragments with sub-angular and angular shape.
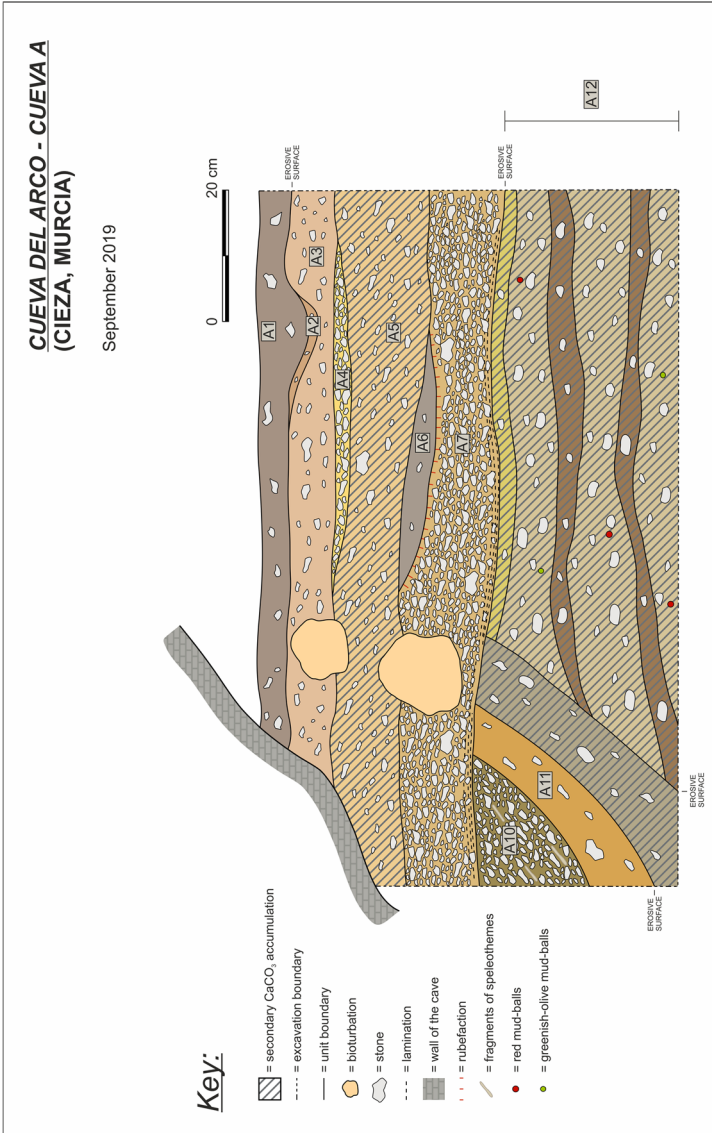
Fig. 6 Cueva del Arco: stratigraphic cross section of Cave A (approximate scale). Drawing and elaboration by J. Armellini and D. Angelucci

The excavation unit I is the Holocene series (GFUs A1 and A2). It is thin, less than 10 cm deep, and its lower boundary is well recognised, even if irregular due to burrowing *ab antiquo*. This unit consists of dark sediment, rich in organic matter and combustion by-products (for the complete description and the correspondence between GFUs and archaeological units see Table 2).

The archaeological units II and III (GFUs A3 to A7) are the Pleistocene series. They are made of sediments with a dominant clastic coarse fraction (limestone fragments, mostly with angular shape) and fine material, the colour of which ranges from yellowish to brownish hues. The coarse inputs are limestone fragments from the cave wall. Among them, frost slabs are detected; they may indicate frost action (among other processes of wall disintegration) and cold, moist climate context. The provenance of fine material is not clear; it may derive from wall disintegration or even from aeolian inputs. The whole set of layers is almost horizontal in inner squares (ex. D19) and dips very slightly outwards (very few degrees) in sq. C19. GFUs A3, A4 and A5 form an almost homogeneous sedimentary set featuring a slightly coarser intercalation (GFU A4). GFU A6 is a few-cm-thick lenticular layer thinning eastwards, mostly composed of combustion by-products (ash and microcharcoal fragments), in particular in its upper part. The lower boundary to GFU A7 shows a 1-cm-thick reddened (5YR4/4) belt due to thermal impact.

Below the excavation unit III, more layers were distinguished (GFUs A10, A11 and A12). They are slightly different from the overlying upper Pleistocene deposit described above. GFU A10 is made up of gravel infilling a sort of canal, the geometry and extension of which are unknown. The outer limit of the canal corresponds to the boundary between GFUs A11 and A12. GFU A11 is a slope-like sediment resting on the erosive boundary, while GFU 12 seems an alluvial-like deposit, probably related to hydric activity of waters flowing in the Barranco de la Tabaquera. No archaeological remains have ever been found from GFUs A10, A11 and A12, and the explanation of their origin and nature is made difficult by the limited extension of the sounding in which they were detected.

No relevant post-depositional dynamics were observed within the Pleistocene succession, with the exception of slight secondary carbonate accumulation, with local weak cementation of some layers (see Table 2).

The succession of Cave A is rather thin (see Fig. 6), which indicates low sedimentation rate through its accumulation. This can be related to the position within the cave (that is, sedimentary inputs in this position of the cave were scarce and mostly coming from cave walls). It should also be noted that the boundary between GFUs A2 and A3 (that is, between the excavation units I and II) is erosive, which means that part of the Pleistocene series has probably been removed by natural or human-related dynamics.

Short Information on the Dating and the Cultural and Faunal Assemblages of Cave A

Excavation unit I includes evidence relating to the latest documented occupations corresponding to a time at the end of the early Neolithic period, from which various pottery fragments have been recovered, some of them decorated by incisions and impressions. We have also found some geometric projectiles from this stage. This

Table 2 Cueva del Arco, Cave A. Field characteristics of excavated units. Key: ang., angular; dev., developed; exc., excavation; fr(s)., fragment(s); hor., horizontal; loc., locally; lst., limestone; mat., material; mod., moderate\moderately; o.m., organic matter; OP, orientation pattern; rnd., rounded; s\- sub-. Bold: distinctive or diagnostic characteristics. Colours are given in moist conditions (unless reported). The deposit at Cave A was described in the test sounding (April 2017) and main excavation sector (September 2018 and September 2019)

GFU	Exc. unit	Geometry	Characteristics	Lower boundary
A1	I	Tabular, parallel to ground surface	Silty loam, few stones (ang. and s\ang. lst. frs., few-mm to few-cm sized, mod. hor. OP), 7.5YR3/3 (10YR7/2 when dry), loose, contains ash	Clear linear, with burrows into GFU A2
A2		Lenticular layer, few-cm thick	Silty loam, few stones (same characteristics as unit 1), 7.5YR3/3, loose, enriched in humified o.m. and combustion by-products	**Sharp, wavy**
A3		tabular layer	Silt with fine to very fine sand, common stones (ang. and s\ang. lst. frs., mostly few-mm large with occasional few-cm frs., mod. hor. OP), 7.5YR5/6, weak	Clear linear
A4	II	**Lenticular intercalation**	**Clast-supported breccia** made up of ang., cm-sized lst. frs., often platy (some are clearly frost-slabs), with well-visible hor. OP; fine mat. is scarce (same as GFU A3), weak,	Clear linear
A5		Tabular layer	Same features as GFU 3 but with slightly larger stones (few-cm-sized) and weakly cemented by CaCO3 with few fine CaCO3 nodules	Clear linear
A6	III	**Lenticular (concave)**	**Silt, 10YR3/2 (dry), with few stones, weak, common ash and microcharcoal frs.**	Sharp concave
A7		tabular layer	Clast-supported loose breccia, loc. partially open-work, composed of ang. cm-sized lst. frs., often platy (some are clearly frost-slabs), fine mat. silt with fine to very fine sand, 7.5YR5/6 (10YR7/3 when dry), reddened belt on top (related to unit 6 thermal impact), weak parallel lamination at bottom	Sharp, erosive

Table 2 (continued)

| GFU	Exc. unit (no)	Geometry	Characteristics	Lower boundary
A10		Lenticular layer	**Clast-supported gravel** (from few mm to max. 4–5 cm), with rnd. to s\rnd. granules and pebbles and occasional ang. to s\ang., mostly lst. (with frs. of speleothemes and weathered pebbles with preserved outer rim, probably from former coatings); fine mat. fills all voids, silty loam (with some sand), 5YR5/7 (7.5YR7/3 when dry), firm, porosity very low, no roots, no o.m. mod. enriched in CaCO₃ (micrite) + thin CaCO₃ pendants below stones	Sharp, dipping inwards
A11		Layer resting on erosive surface	Clayey silt, 4YR4/7 (5YR5/6 when dry), with few stones (fine lst. frs., s\rnd. and s\ang.); apparent fine s\ang. blocky mod. dev., firm, porosity very low, no roots, no o.m.	**Sharp, on erosive surface dipping inwards**
A12		Set of clastic layers, vaguely stratified, with slightly irregular layers dipping inwards with very low angle	Poorly selected heterometric gravel, with variable support (mostly matrix-supported, loc. almost clast-supported); clasts are lst. frs. from few mm to max 7 cm, s\ang. to s\rnd., OP random; fine mat. is sandy-silt, 4YR4/7; features: occasional irregular intercalations of very coarse sand and fine granules, sometimes clast-supported; intercalations of clayey loam, 4YR4/6, in 2–4-cm thick irregular layers with few stones (lst. frs., often s\rnd.); a 3-cm-thick whitish CaCO₃ crust, mostly powdery, at its top; few fine 'mud balls' of dark red compact clay or olive-greenish yellow clay and stones with outer coating preserved and inner core weathered, is weakly enriched in carbonate and devoid of o.m. and roots	Not observed
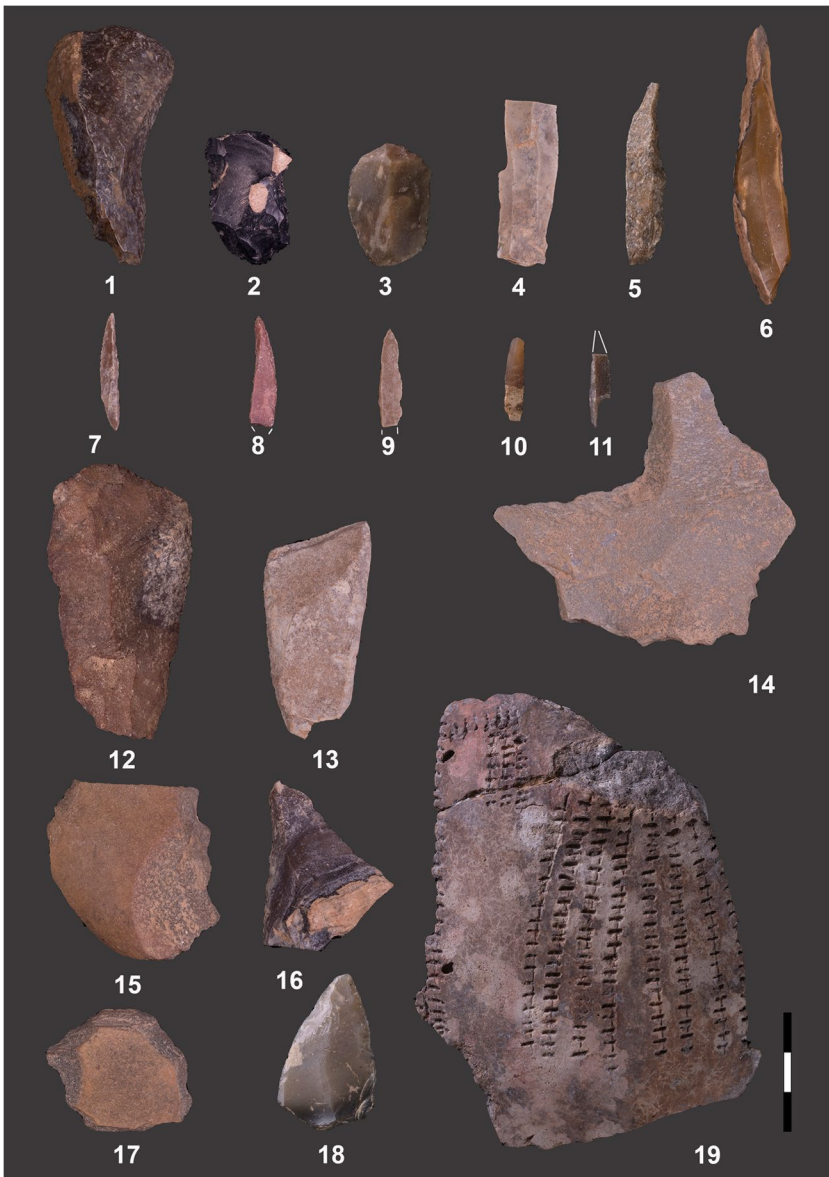
Fig. 7 Cueva del Arco: selection of representative finds from Cave A. End-scrapers (**1–3**); burin (**4**); Gravette points (**5–6**); microgravette points (**7–9**); backed bladelet (**10**); Solutrean shouldered point (**11**); Mousterian side scrapers (**12–13** and **15–18**); Levallois flake (**14**) and Neolithic potsherd decorated by incisions and impressions (**19**). Provenance: numbers **1** to **11** from excavation unit II; numbers **12** to **18** from excavation unit III; number **19** from excavation unit I. Scale bar measures 3 cm

is a layer that has been significantly affected by surface erosion and by the burrows of small mammals, which has prevented us from documenting these occupations in greater detail.

Below these occupations, in the lower part of excavation unit I, and also highly affected by erosion and burrowing, there is an Evolved-Solutrean II occupation, mainly attested to by the occurrence of two shouldered points (Fig. 7; see Fortea and Jordá, 1976; Villaverde and Peña, 1981). According to the regional sequence, this could be placed at *c.* 23,000–20,500 cal BP (Villaverde, 1994). This occupation is very interesting as it corresponds to the style of the existing rock art evidence in Cave E. Unfortunately, no radiometric dating is available for this layer.

The next documented occupation is assigned to the Gravettian and refers to excavation unit II. Unlike the previous ones, it is well preserved, as shown by the occurrence of several hearths in primary position. The main hearth (H1) is 60 cm long by 40 cm wide and is built on a slight basin that has some small/medium-sized clasts inside (see Fig. 8). There does not seem to be a boundary marked by stones, although about 30 cm from the structure some degree of emptying of the hearth has been documented.

Among the materials associated with these structures, various Gravette and Microgravette points, as well as backed items clearly linked to the Gravette period, are the outstanding features. This is confirmed by the three radiocarbon dates obtained from both hearth H1 and the archaeological level, all between 30,870 and 30,070 cal BP (ETC-67833, ETH-67834 and VERA-7068, see Table 3). The faunal remains from these levels are being studied by Dr. C. Real (Universitat de Valèn-cia), and it seems that, apart from the great predominance of rabbits (a common occurrence in the Iberian Mediterranean), the *Capra pyrenaica* (Iberian ibex) is the dominant animal in the group, together with other ungulates and some carnivores (ongoing study).

Below these occupations, a thin level of gravel has been documented at some points of the cave, but we cannot rule out as corresponding to a previous Upper
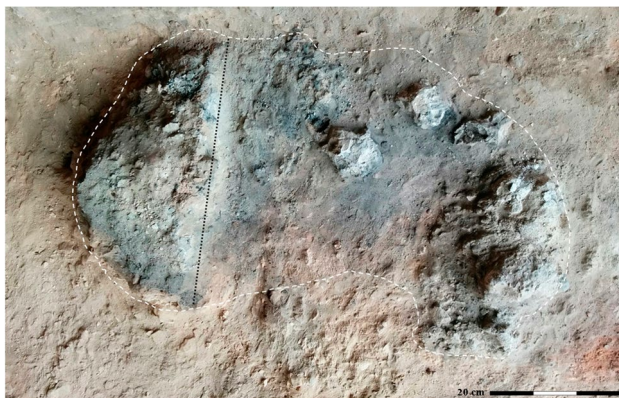

Fig. 8 Cueva del Arco, Cave A: Hearth H1 during excavation. The white dashed line indicates the outer boundary of the fire feature. Scale bar measures 20 cm

Table 3 Cueva del Arco, Cave A. Radiocarbon dating. Radiocarbon dates were obtained at the laboratories of ETH (Zurich, Switzerland) and VERA (Vienna, Austria). All samples were pretreated using the ABOx-SC (acid-base-oxidation-stepped combustion) method (Brock and Higham, 2009). The results were calibrated with OxCal (version 4.4)

Sample		Provenance			Description	Result		Cal age (a cal BP)	Remarks
Label	Lab. ref	Exc. unit	GFU	Year		Date (a bp)	δ¹³C (‰)	2σ	
Arco-1	ETH-67833	II	A5	2016	Charcoal Juniperus sp.	26193 ± 104	−20.5 ± 1	30801–30148	Hearth 1
Arco-2	ETH-67834	II	A5	2016	Charcoal Juniperus sp.	26279 ± 106	−21 ± 1	30870–30233	Hearth 1
Arco C18-SW	VERA-7068	II	A4+A5	2018	Charcoal Juniperus sp.	26151 ± 172	−21.4 ± 1.4	30846–30068	
Arco 284-D17-NW	VERA-7063	III	A5–A6	2019	Charcoal Juniperus sp.	28617 ± 287	−27.8 ± 1.1	33780–31948	Boundary II-III (fire feature)
Arco 134-C18-NW	VERA-7064	III	A6+A7	2019	Charcoal Pinus nigra- sylvestris	> 50368	−27.3 ± 0.6		Dates out of range for calibration (minimum ages)
Arco C17-NE	VERA-7065	III	A6+A7	2018	charcoal Juniperus sp.	45699 ± 1931	−14.1 ± 4.2		
Arco D18-SW	VERA-7066	III	A6+A7	2018	Charcoal Pinus nigra- sylvestris	54594 ± 8522	−29.6 ± 0.8		
Arco B15-NW	VERA-7067	III		2017	Bract of pine cone	7101 ± 35	−23.5 ± 0.7	8010–7845	

Palaeolithic occupation. It marks the contact between archaeological units II and III. In fact, just below hearth H1, some elusive finds were recovered—such as a small bladelet with very fine retouch which we hesitate to classify as a Dufour type. Together with the existence of a radiocarbon date of 33780–31948 cal BP (VERA-7063, see Table 3), this suggests that there may have been some occupation in the Aurignacian which until now could not be properly documented.

Below these Upper Palaeolithic occupations, there is an important sedimentary package assigned to the Middle Palaeolithic, excavated as a whole as archaeological unit III. This unit exhibits clear lithological differences from the upper one. Together with the change in stone tools, this allows us to clearly assign it to the Mousterian period. In relation to the materials recovered, the large proportion of retouched tools in the lithic industry is striking. Scrapers (lateral, transversal and convergent) are extremely abundant at the percentage level, together with various Mousterian points and some notched and denticulated pieces (Fig. 7). The extraordinary quality of the manufacture and retouch of many of these pieces is also worth highlighting. More detailed studies of this lithic assemblage, together with the recovered bone and plant remains, are ongoing, but these industrial characteristics are nonetheless surprising. This layer has been dated by radiocarbon yielding a minimum age of *c.* 45–55,000 ^{14}C ka (VERA-7065, VERA-7066 and VERA-7067, see Table 3).

Cueva del Arco: Cave D

Cave D is filled with a thick sedimentary succession that, unfortunately, yielded almost no archaeological record dating from the Palaeolithic.

Stratigraphy of Cave D

The succession of Cave D consists of two distinct series, easily distinguished thanks to their sedimentary characteristics and to the sharp boundary that separate one from the other (see Table 4 for complete description and Fig. 9): unit D1 is the Holocene succession and units D2 and D3 constitute the Pleistocene deposit.

Unit D1 contains common stones, is enriched in organic matter and shows evidence related to Holocene soil formation (mainly structure development), especially at the cave mouth. Unit D1 was further divided into two GFU, D1a and D1b, which respectively correspond to the horizons A and BC of the soil that has developed on part of the succession and that has also affected underlying units.

Units D2 and D3 form the Pleistocene succession. Under the microscope they broadly show a prevalence of angular silt-sized siliciclastic components (quartz and feldspar, mainly) in the lower part of the deposit, while clastic carbonate components (fragments of limestone, including frost-slabs and carbonate minerals; see Fig. 10a and b) increase upwards (i.e., in unit D2). Among biogenic and anthropogenic components, rare charcoal fragments, few bones and shell fragments were detected (see Fig. 10c). The fine material is brown, made up of micrite and with crystallitic b-fabric. The pedofeatures are scarce and related to biological activity and accumulation of secondary calcium carbonate. Specifically,

Table 4 Cueva del Arco, Cave D. Field characteristics of excavated units. Key: see Table 2. Bold: distinctive or diagnostic characteristics. Colours are given in moist conditions (unless reported). The deposit at Cave D was described from the longitudinal cross-section from squares B6-B7 and C8 to C13, in September 2017 and September 2018

| Unit	Geometry	Characteristics	Lower boundary
D1a	Tabular, parallel to ground surface	Silty loam, scarce to common stones (quantity varies laterally, lst. frs. with variable size), 10YR3/2, mod.-dev. fine granular structure, **common humified o.m.**, porosity mod., common roots	Clear, linear, parallel to ground surface
D1b	Tabular	Silty loam, common stones (as in unit 1a), 10YR2/1, weakly-dev. fine granular structure, mod. humified o.m., porosity mod., few roots, contains **thin lenses of ash and other combustion by-products**	**Sharp, distinct, with burrows into unit 2a**
D2a	(See Fig. 8)	Loamy silt, frequent stones (c. 40%), lst. frs. from few mm to 4 cm (average 1 cm), mostly ang. (slang. stones are scarce), sometimes platy (some are clearly frost-slabs), weak OP from hor. to few degrees southwards, **7.5YR5/5** (9YR6/5 when dry), porosity low, few roots, mod. secondary CaCO$_3$ (micrite) accumulation, few fine (1-4 mm) CaCO$_3$ nodules	Clear
D2b	(See Fig. 8)	Silty loam (clay fraction slightly increases downwards), frequent stones (same characteristics as unit 2a), **7.5YR5/5** (10YR6/6 when dry), porosity very low, not affected by secondary carbonate accumulation	Clear
D2c	(See Fig. 8)	Silty loam, few stones (same characteristics as units 2a and 2b except for the absence of frost-slabs and no preferential OP), **7.5YR5/6** (10YR6/6 when dry), no soil structure, porosity very low, not affected by secondary carbonate accumulation	Gradual, poorly-distinct
D3	Filling inner part of cave entrance	**Silt** (almost homogeneous through whole thickness, ca. 170 cm), very few stones (mostly 4-8 mm, occasional larger stones, 4–5 cm), 10YR5/6 (10YR7/5 when dry), massive, porosity very low, rare roots in its lower part, patchy secondary carbonate accumulation, local weak lamination	Sharp to bedrock
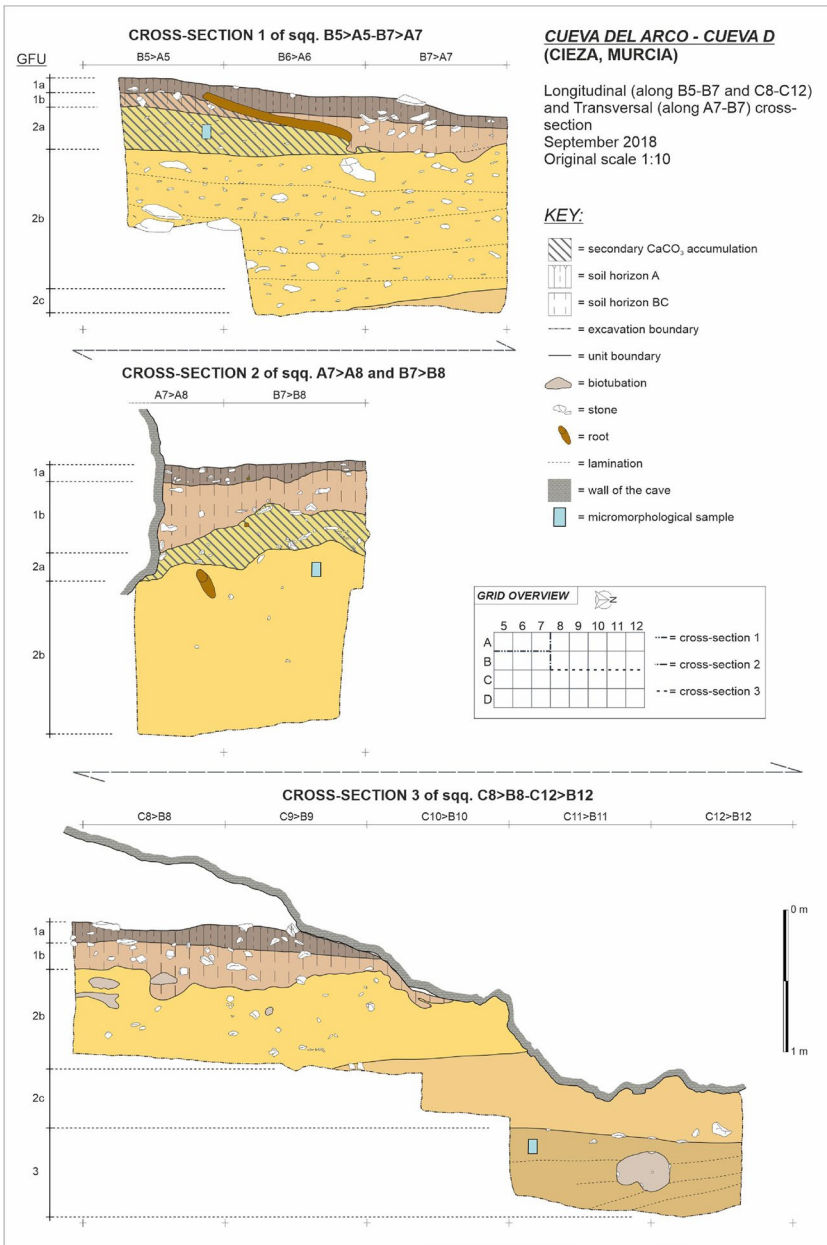
Fig. 9 Cueva del Arco: composite stratigraphic cross-sections of Cave D. Drawing by J. Armellini and D. Angelucci, elaboration by J. Armellini

they include infillings of biopores and passage features, few silt coatings around limestone fragments (see Fig. 10d) as well as micrite coatings and hypocoatings on void surfaces (the last one only in unit D2a, see below).

Unit D2 (further subdivided in GFUs D2a, D2b and D2c) is mainly composed of coarse angular fragments and shows evidence of soil formation. Unit D2a is a
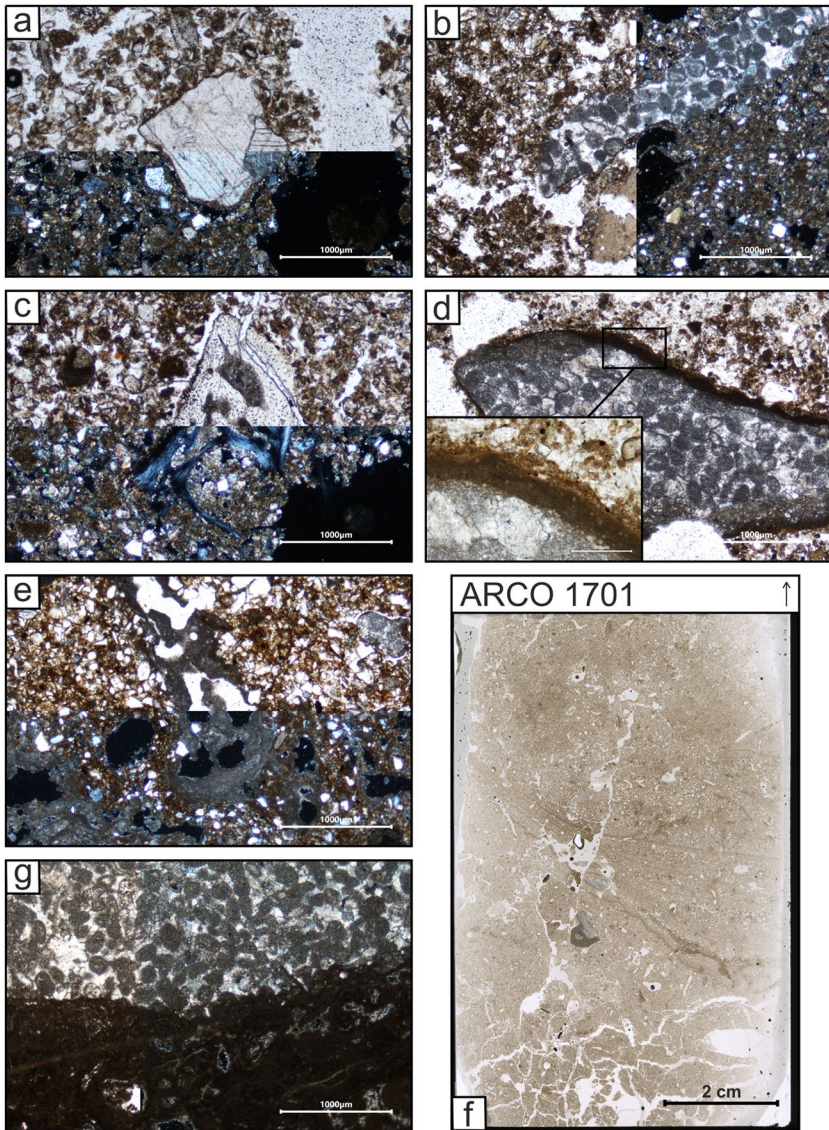
Fig. 10 Cueva del Arco: micrographs from Cave D. **a** twinned calcite crystal (TS ARCO1701; top: PPL, bottom: XPL); **b** frost slab made of local carbonate rock (a pelsparitic limestone) (TS ARCO1701; left: PPL, right: XPL); **c** bone fragment; notice the haversian canals (TS ARCO1701; top: PPL, bottom: XPL); **d** fragment of limestone with silt coating (TS ARCO1902; PPL); **e** secondary calcium carbonate accumulation as micritic coatings on a void surface (TS ARCO1903; top: PPL, bottom: XPL); **f** scan of ARCO1701 thin section; notice the lamination in the centre of the image (PPL); **g** fragment of local carbonate rock with exolithic crust developed on its surface (TS ARCO1903; left: PPL, right: XPL).Micrographs and elaboration by J. Armellini

Fig. 11 Cueva del Arco: profile from the test pit dug at Cave E. Notice the sharp, erosive contact between units E1 and E2. Dashed-lined rectangles indicate the positions of undisturbed samples. Picture by I. Martín, elaboration by J. Armellini
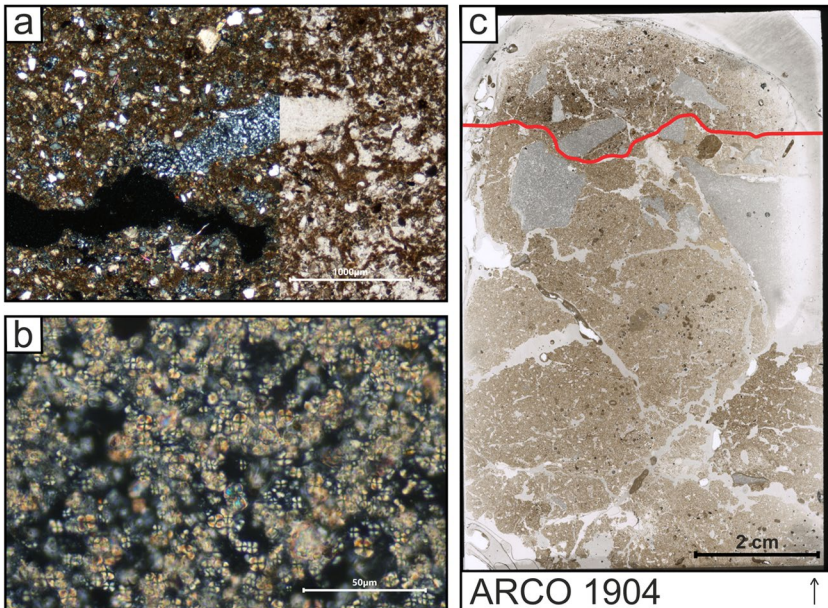

Fig. 12 Cueva del Arco: micrographs from Cave E. **a** infilling of gypsum in a channel; the gypsum crystals measure 10–20 μm (TS ARCO1904; left: XPL, right: PPL); **b** calcitic spherulites (TS ARCO1901; XPL); **c** scan of ARCO 1904 thin section; the red line indicates the human-made erosive surface between units E1 and E2 (PPL). Micrographs and elaboration by J. Armellini

2B horizon developed at the cave entrance. Soil structure is clearly visible in thin section in form of granular aggregation, in association with common biopores. The most relevant pedofeature in unit D2a is connected to the accumulation of secondary carbonate calcium in form of micrite coatings and hypocoatings (see Fig. 10e). Unit D2b is a 2Bw soil horizon. Under the microscope it shows evidence of soil formation, mainly recognisable in its microstructure. Unit D2c is the transitional layer to the underlying unit D3.

The bottom unit, GFU D3, is composed of silt with few stones, quite homogeneous through its thickness, even if secondary carbonate accumulation, weak lamination (see Fig. 10f) and discontinuous stone-lines locally occur. Slight evidence of sin-depositional biological activity is also present.

Short Information on the Dating and the Cultural and Faunal Assemblages of Cave D

In Cave D, the decision was made to carry out an initial excavation because of all the features it had pointing to Palaeolithic occupations. The thickness of the deposit, its location at the bottom of the Cueva del Arco complex, right next to Cave E (with Palaeolithic rock art), and the possibility that it was a larger cavity that had filled up, led us to first carry out a small test pit, later an excavation of the upper part of the stratification (Neolithic), and finally an excavation in extension towards the bottom of the cavity to try to confirm its original depth.

These excavations have allowed us to confirm the existence of a surface occupation level from the end of the early Neolithic period, possibly the same one as is documented in Cave A.

Below this layer, the change in sedimentation is very pronounced (see above) and, despite having recovered several scattered Palaeolithic materials (lithic industry, ornaments and fauna), it has not been possible to determine the presence of any preserved level of occupation. Everything seems to be the product of reworking from outside the cavity. The features of the materials point tentatively towards an attribution to the Solutrean or the Gravettian periods, although there is no clear evidence allowing us to confirm this.

Cueva del Arco: Cave E

A 1-m^2 test pit was excavated at Cave E in 2019, at the position where the hind is depicted on the wall, in order to verify the possible presence of archaeological sediment.

Two units were detected in the sounding (Fig. 11). GFU E1 is a set of horizontally laminated layers enriched with organic matter (0–7 cm). They consist of very-dark-grey silty loam, with fine sand, a few cm-sized limestone fragments and common organic matter; the lower boundary is sharp, linear and horizontal. The lower layer (GFU E2, explored on a total thickness of 1 m) is massive brown silt with low porosity, occasional roots, and scarce angular limestone fragments (max. size 12 cm), scattered on its whole thickness. No apparent organisation was observed unless for thin post-depositional intercalations of gypsum (Fig. 12a).

No evidence of human occupation has been detected in the deposit. Nonetheless, preliminary observation of thin sections from the GFU E1 has shown the presence of combustion by-products (microcharcoal fragments and ash) and of biogenic inputs (spherulites, Fig. 12b). The absence of evidence does not permit an understanding of whether the Cave E was only used for symbolic practises—in particular the production of the rock art detected there (see above)—or if later human activities removed previously-existing archaeological sediments. The latter could be suggested by the boundary between the upper and the lower units, which is an erosive interface. Its regularity indicates an artificial, human-made origin as a surface for levelling the cave's ground floor (Fig. 12c), perhaps by shepherds who used the caves as a shelter for flocks of ovicaprines.

Discussion

Cueva del Arco: a Relevant Site for the Palaeolithic of the Southern Iberian Peninsula

In this paper, we present for the first time a new prehistoric site complex in the southern Iberian Peninsula, Cueva del Arco, mainly focusing on its geoarchaeological characteristics.

Fieldwork carried out at the site has shown that at least two *loci* (Cave A and Cave D) preserve Palaeolithic and Neolithic record, while other locations (such as Cave E or Arco II) probably featured Palaeolithic deposits, which were removed in later times. The information collected at the site is still preliminary, nonetheless the data suggest that Cueva del Arco can be a reference site for the Iberian Palaeolithic. The site is located along one of the main valleys dissecting the margin of the central Iberian plateau (the Meseta). Palaeolithic sites are already known across the Almadenes gorge, and Cueva del Arco is located along a secondary valley draining towards the gorge, at a short distance from it. Similar patterns of site location are also detected in nearby valleys, for instance in the Mula drainage basin, where caves and rock shelters have been recently explored (see Angelucci et al., 2013, 2018; Zilhão et al., 2016, 2017; Deschamps et al., 2022).

Cueva del Arco looks promising for several reasons. First, the concurrent presence of archaeological deposits and rock art at the site, which is something quite uncommon in Mediterranean Iberia. At the same time, the huge extent of surface morphologies related to karst dissolution can be an indicator of the existence of a well-developed subterranean karst network. Another point of interest is the remarkable Middle and Upper Palaeolithic archaeological record, which features abundant lithic and faunal assemblages and well-preserved fire structures.

Site Formation

As far as formation processes are concerned, most of the deposits observed at Cueva del Arco exhibit, on average, the typical features of clastic accumulation within

Mediterranean caves and rock shelters (see Bailey and Woodward, 1997 or Angelucci et al., 2018): crude stratification; abundant coarse fraction, mostly provided by angular limestone fragments derived from local bedrock; fine material filling interstitial voids among coarse elements; poor textural sorting; local enrichment of secondary calcium carbonate and local disturbance by past biological activity. Nonetheless, the basal units explored at Cave A and Cave D show characteristics that depart from this model.

At Cave A, the upper complexes (excavation units I, II and III) form a set of layers which are grossly horizontal and mostly formed of natural inputs (limestone fragments from the rock shelter and fine material, mainly silt). Human inputs are subordinate, except for the top of the excavation unit III (GFU A6), which is a clear fire feature. Available radiocarbon dates show that the excavation unit II was formed at about 30 ka cal BP, with three statistically identical measures (ETC-67833, ETH-67834 and VERA-7068, see Table 3). The hearth at the top of the excavation unit III (GFU A6) is slightly older, as its age falls in the time interval *ca.* 33.8–32.0 ka cal BP (VERA-7063, Table 3). No significant stratigraphic discontinuity nor variation of sedimentary inputs and characteristics were detected between the hearth and the underlying excavation unit III. Nonetheless, radiocarbon dates indicate a prolonged hiatus between them, as all the measures from unit III (VERA-7064, −7065 and −7066) are minimum ages older than 55 ka ^{14}C bp (Table 3), thus suggesting that the early moments of cave occupation may refer to the early MIS 3 or to the MIS 4. These results show that the Cave A succession was characterized, as far as the excavation units II and III are concerned, by low sedimentation rates or even by non-depositional hiatuses that are not recognisable nowadays.

Excavation unit III lies on an erosive surface that truncates the bottom layers of the Cave A succession. The bottom layers correspond to GFUs A10, A11 and A12 and are archaeologically unnamed as no archaeological remains were collected from them. They exhibit rather distinct features once compared with the succession above the excavation units I, II and III. They are mostly made up of gravels, with intercalations of sand and silt beds, which are allochthonous with respect to the rock shelter. The composition and geometry of these beds (especially of GFU A12) indicate that their formation is the result of hydric, torrential activity that took place in the Barranco de la Tabaquera, at a time when the valley was hydrologically active and the water course was probably flowing at a slightly higher elevation than the present one. The age of these sedimentary units is unknown and may well refer to MIS 4 or MIS 5, during which significant hydrological activity is recorded at other sites of the Segura drainage basin, such as Cueva Antón (Zilhão et al., 2016). More data are needed to truly understand these early phases of sedimentary accumulation at Cave A.

The deposit of Cave D also shows some variability of its sedimentary and post-depositional characteristics through time. While the upper units D1 and D2 are mostly made up of coarse limestone inputs from the cave entrance, the lower unit—GFU D3—is distinct. The bulk of the layer D1 and D2 clearly comes from the disintegration of the rock shelter walls, as indicated by the lithology of the limestone fragments and occasional presence of exolithic crust (*aka* rock coating, see Fig. 10 and also Angelucci et al., 2023). The fine material, mostly micrite, is also derived from the

disintegration of the encasing bedrock. After the accumulation of the succession, its upper part was subjected to a relatively prolonged phase of stability, which is responsible for the development of soil horizons at its top: an A horizon (GFU D1) and a poorly developed cambic B horizon (GFU D2a), the characteristics of which are well visible at the cave mouth and fade inwards. The outer portion of these units, nearby the rock-shelter dripline, was also affected by significant secondary carbonate accumulation. No dating is available for this succession. The upper part (GFU D1) has yielded early Neolithic assemblages, which help to ascribe it to some moment of the middle Holocene, while the underlying unit D2 contained occasional reworked Upper Palaeolithic chert artefacts, thus suggesting a possible late Upper Pleistocene age.

The GFU D3 was only detected in the inner sector of the cave. This unit is at least 1 m thick, consists of yellow silt with very few limestone fragments and is locally laminated. Field and microscopic observation show that the silt material incorporates a subordinate, but still relevant, quantity of siliciclastic minerals, which are not detected within the local bedrock. The sedimentary characteristics thus indicate that unit D3 is slope sediment coming from the outside. Most probably, the sedimentary sources of this material are former surface sediments or soil covers that were eroded from the surrounding area and washed into the cave through surface flow, most probably run off or even mud flow, at some specific moments, as the presence of silt coatings may indicate (see Angelucci and Zilhão, 2009). The thickness of unit D3 may point to a relatively long phase of surface denudation or a relevant episode that affected the area at some moment, due to climatic or environmental forcing or a change of karstic circulation. Unfortunately, no dating is available for unit D3 and no remains have ever been collected from it.

Concluding Remarks

The first data collected from the caves of the Cueva del Arco complex confirm its relevance as a site of archaeological interest. The site includes at least four caves with evidence of human occupation. The most ancient phases are attested at Cave A and probably pre-dates MIS 4, during which the local watercourse (Barranco de la Tabaquera) was hydrologically active and accumulated sediment into the cave. The earliest evidence of human presence is recorded at the same cave, which was occupied by groups of Neanderthals earlier than *c.* 55 ^{14}C ka. Surprisingly, no traces of Middle Palaeolithic assemblages have been found in the other caves until now. This is one of the issues that will be examined through the continuation of fieldwork and analysis, as it may depend on surface dynamics rather than specific decision-making by Neanderthals.

Upper Palaeolithic human presence is registered at four *loci* at Cueva del Arco. Cave A was possibly occupied by Aurignacian groups, certainly during the Gravettian and the Solutrean, on a time span of *c.* 10,000 years. The infilling of Cave D also features artefacts belonging to these periods but in a secondary position. Rock art is found in Cave E and Arco II and has been ascribed to the Solutrean and the Magdalenian, respectively (Salmerón Juan et al., 1998). In both caves, no evidence of archaeological stratification has been detected yet; field data have shown that the Pleistocene deposits from both caves were partly affected by erosion. Still, the

information derived from the cultural assemblages and rock art demonstrates that the site complex was visited during the whole duration of the Upper Palaeolithic.

Human occupation has also been recorded at a more recent Holocene phase, specifically during early Neolithic in both Cave A and Cave D.

Given these results, the caves at Cueva del Arco disclose remarkable potential for providing new insights into the behavioural patterns of Neanderthals and the Middle-to-Upper Palaeolithic transition.

Data Availability Datasets are available on request from the corresponding author.

Author Contribution Ignacio Martín-Lerma and Dídac Román: conceptualisation, investigation (data collection and elaboration), writing (original draft preparation and review) and funding acquisition. Jacopo Armellini: investigation (data collection and elaboration), writing (review and editing). Noelia Sánchez Martínez: investigation (data collection and elaboration). Diego E. Angelucci: conceptualisation, investigation (data collection and elaboration), writing (original draft preparation, review and editing) and supervision (corresponding author).

Declarations

Ethical Approval Not applicable.

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